

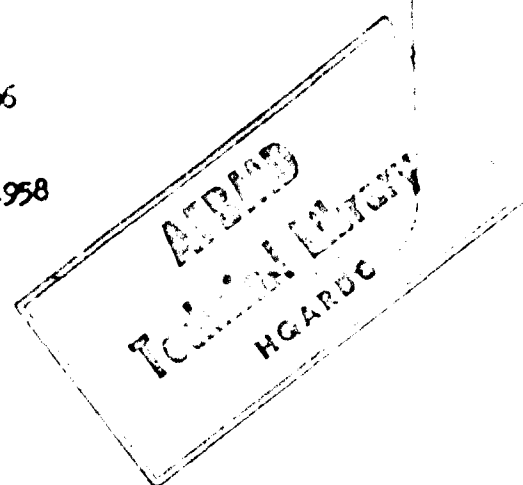
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EXPERIMENTS IN INTERPLANETARY BIOMIGRATION
AND SPACE CONTAMINATION*

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P-1406

June 16, 1958



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* Paper (in shorter version) read at the Symposium on Possible Uses of Earth Satellites for Life Sciences Experiments, Washington, D. C., May 14-17, 1958. Sponsored by the American Institute of Biological Sciences, The National Academy of Sciences, and the National Science Foundation.

The RAND Corporation

1700 MAIN ST. SANTA MONICA, CALIFORNIA

The development of space flight capability provides new approaches to some of the fundamental problems in biological science. Saliently, space penetration not only supplies the facility to study terrestrial life forms in radically different environments, but also presents the fascinating possibility of the encounter of non-terrestrial life forms which may be studied in their native and other environments. Such penetrations afford revolutionary means for increasing understanding of the nature of the life process, how it originated, how it evolves and functions, and what forms it may assume under widely different environmental conditions.

Some of the specific questions which may be examined as a result of space flight capability include Biogenesis: Whether life originated on the earth, whether it originated independently on other planets, or whether it may have migrated from planet to planet as suggested in the panspermia hypothesis. Parabiology: Assuming indigenous life forms are encountered on other planets, their degree of organization, their evolutionary history, their structure and chemistry related to their autecology, the functioning of their virginal ecological complexes, and finally their interactions with terrestrial life. Generalized Ecology: The behavior of terrestrial organisms in alien environments, physical limits to their survival, and the appearance of possible new ecological parameters and their effects. Interplanetary Bionigration: Viable micro-organisms* being transported from planet to planet by natural forces and the intentional and/or inadvertent transport of micro-organisms by artificial means.

Although it may be many years before studies such as these can be

* Throughout this paper the term micro-organism is used to refer to any terrestrial viable particle, as opposed to the more general term bion which is used for the corresponding para-biological entity.

successfully pursued, some preliminary experiments and precautions, as will be proposed in this paper, should be undertaken in the immediate future with existing satellite and space flight capabilities in order that the opportunities for these future basic studies not be obliterated.

Among the earliest ideas on interplanetary biocmigration were the proposals of Sales-Ouyon de Montlivault in 1821 that life on earth originated from seeds falling from the moon. In 1865 H. E. Richter⁽¹⁾ hypothesized that life has existed in the universe as long as matter has existed and that space is filled with basic life particles. When one of these particles, such as a spore, falls on a planet with favorable environmental conditions, the planet would in time be covered with a large number of suitably adapted higher life forms, thus combining the theories of evolution and panspermia. Others who speculated concerning the panspermia hypothesis were Lord Kelvin (William Thompson) in 1871, Ferdinand Cohn 1872, and H. v. Helmholtz in 1884.⁽²⁾ But the most extensive contributor to the hypothesis was S. Arrhenius⁽³⁾ who made quantitative estimates of times required for spores to traverse interplanetary and interstellar space propelled by radiation pressure and discussed survival probabilities of organisms under space conditions. In recent years little that can be considered new has been contributed to interplanetary biocmigration except the experiments of Lipman⁽⁴⁾ attempting to determine the biophoretic properties of meteorites. The best current evaluation of the panspermia hypothesis is probably that of Oparin.⁽⁵⁾

With the advent of modern concepts on the synthesis of macromolecules and the origin of life, the panspermia hypothesis was condemned to obscurity by experimentally acceptable theories of biogenesis. Nonetheless, there

has never been sufficient data to prove or disprove this hypothesis; so the advent of space flight invites scientific re-examination of panspermia concepts. However, the space flight capability, which allows the re-examination of the panspermian hypothesis by making feasible experiments for testing the survival of micro-organisms in space and for sampling the actual numbers (if any) of viable organisms in various parts of space, modifies the probabilities in panspermia. For while automigration of micro-organisms (i.e., transport of micro-organisms or bions from the surface of one planet to another abetted solely by natural forces) may be highly improbable, interplanetary biomigration which is in part aided by space flight operations may occur much more readily than would be desired or planned. This introduces to the problem of the determination of the probability of automigration, the determination of the probability of ancillary migration and the probability of the inadvertent interplanetary transport of organisms by artificial means, which we might term space contamination.

In addition to the investigation of the likelihood of auto- and ancillary migration of viable micro-organisms, ^{experiments suggested to determine} experiments in the survival potentials of micro-organisms under various space conditions, ^{to} ~~would~~ establish the extent to which space sterilization of interplanetary instrument probes and other space vehicles may be relied upon to prevent the infecting of other celestial bodies, (or the infecting of the earth with alien life by returning probes), and, ^{to determine} whether further sterilization procedures would be required. ~~Experiments exposing micro-organisms to space conditions would also have the utility of detecting unsuspected space effects, i.e., effects which would be observed by instruments only fortuitously. This is because instruments designed to measure specific parameters have less utility in~~

the detection of unknowns than organisms which possess more ubiquitous sensors. The modifications induced in micro-organisms exposed to actual space conditions (~~vis-a-vis~~ space-simulated conditions) as learned from the above experiments may also have bearing on our knowledge of biogenesis and evolution.

The essence of the contamination problem is that the probability of the infection of other planetary bodies by a biophoretic planet will be altered if the natural forces which can move a bion from one planet to another are aided at some stage (or stages) by artificial means. Thus the planetary contamination question is not merely how to disinfect a space craft. It is a question basically involving the larger concept -- in what way does any space operation undertaken by man alter the nature of space as a barrier or highway for interplanetary bi migration governed solely by natural forces; and how may inadvertent alterations of natural transport processes be controlled and minimized.

The implications of this broader context are illustrated by the fact that in having launched even satellites, the probabilities of natural interplanetary biomigration may already have been radically altered. Hibbs⁽⁶⁾ has reported that the skin temperatures of the Explorer I (1958 α) in space ranged from -5°C to 70°C , well within viability preserving limits, and surprisingly that parts of the skin of the Explorer did not rise above 47°C during the aerodynamic heating phase. It is quite conceivable that at the present time there are on the outer surface of the Explorer some viable organisms. The probability of these being freed of the satellite and being propelled by radiation pressure, the Poynting-Robertson effect, or some other natural force, to another celestial body may be quite remote. But

nonetheless, it is by no means the same probability as the probability for an organism to be taken by natural forces from the surface of the earth to Explorer's orbit and then carried by radiation forces to other bodies.

But of much more significance, space programs within the not too distant future will plan flights of instrumented probes to explore the atmospheres and surfaces of other planetary bodies, such as Venus and Mars. These probes are potential contaminators of these planets even though landings may not be made. And it is not so much from outside skins as from accidental crashing of unsterile probes that danger of contamination arises.

We may examine the contamination problem by dividing it into the following phases:

1. The probability of an organism from the earth's surface reaching the exosphere by convection, impact transfer, etc.;
2. The probability of an organism in the exosphere acquiring a hyperbolic orbit by radiation pressure, impact, or some other accelerating mechanism;
3. The probability of a hyperbolic orbit leading to positions in space favorable to the organisms being swept up by another planet;
4. The probability of capture and descent to the surface of another planet; and
5. Most basic, the probability of survival of the organism at each stage.

The probability of successful interplanetary biomigration will be the product of the probabilities of these separate natural events; or, as man's space operations extend, the probability of each natural event must be replaced by the new probability introduced by the corresponding artificial

event in space flight:

- a) The probability of an earth micro-organism reaching another planet when phases No. 1 and No. 2 above are supplanted by artificial satellite transport through the exosphere with the micro-organism being subsequently freed from the satellite by natural forces.
- b) The probability of infecting another planet by a vehicular probe passing near the planet hyperbolically.
- c) The probability of infecting another planet by a satellite probe circling that planet.
- d) The probability of infecting a planet with an atmospheric probe.
- e) The probability of infecting a planet with various types of vehicular landings (including an inadvertent crash).

In order to make some progress in estimating the magnitude of space as a barrier to natural biomigration and acquire an idea of what the component probabilities may be, several experiments, both laboratory and satellite-borne, suggest themselves.

We may think of three categories for such experiments:

1. Experiments designed to ascertain the survival of micro-organisms under various atmospheric and space conditions.
2. Experiments to determine the astrophysical properties* of micro-organisms.
3. Actual samples taken at various levels of the atmosphere and exosphere to determine the presence (if any) of micro-organisms. And later,

* By astrophysical properties are meant absorption coefficients, masses, sizes, etc. In general, those properties which would give information on how the organisms would react to radiation pressure, fields, and other forces affecting their transport and physical state in space.

samples of the atmospheres and soils of other celestial bodies, as suggested by Fern and Lederberg. (7, 8)

The survival studies could be conducted both in the laboratory and in space. The laboratory experiments would entail subjecting bacteria, viruses, spores, seeds to space simulated conditions to determine the survival limits of organisms to wide ranges of intensity of various radiations such as X-rays, γ rays, UV, and high energy particles, the survival limits in temperature, absence of atmosphere, moisture, etc.

The space survival tests should include the investigation of the survival characteristics of various micro-organisms such as bacteria, viruses, plant spores and seeds under actual conditions in free space. Comparisons should be made at a large range of distances from the earth's surface to determine whether certain features of the space environment vary in their sterilization properties due to the effects of 'local' terrestrial anomalies such as the earth's magnetic field. Van Allen's newly discovered shell of particle radiation may be an example of such a local effect. (9) Comparative tests should also be made inside and outside the earth's shadow. In addition the survival characteristics of micro-organisms floating free in space should be compared with those of life forms both placed on the outside skins of satellites and placed inside of satellites. Outside forms survival chances may vary considerably. They may be shielded by structural parts imbedded in paints of various albedoes or in other surface coatings, e.g., in heat-resistant porous ceramic materials. All conditions where potentially surviving micro-organisms may subsequently be either detached and make their way into some planetary atmosphere or survive a probe's penetration of an alien atmosphere should be scrutinized.

The likelihood of an organism surviving free in space is probably less than the likelihood of survival partially sheltered by the space craft coating. Hence if no organism survives the latter partially sheltered environment, it could be concluded that none would survive free in space. So, only, in the event of survival of micro-organisms hitchhiking on outer skins would it seem important to attack the experimentally more difficult problem of survival in free space.

The exposure of the laboratory selected micro-organisms to space conditions on the outside of the satellite might be accomplished by removing portions of the satellite shell and exposing to outer space previously inoculated samples of space craft coatings (porosities and albedoes) contained in the satellite. The satellite shell covers could be replaced after suitable exposure time, and the exposed samples then compared with unexposed samples retained within the satellite and with earth retained samples for analysis of their respective survival properties. Instrumentation to compare the satellite samples and telemeter the data to earth could perhaps be designed, but it is best to think of this type of experiment as one to be carried out with a recoverable satellite. (This, however, has the disadvantage that space flight agendas call for moon shots before recoverable satellites.) Such experiments would also contribute to more accurate knowledge of the space environment in that they might serve to detect unknown radiations and other effects. Later, more sophisticated experiments would study not only survival potentials but alteration of organisms by radiation effects in space. It is conceivable, for example, that the high UV intensity in space may be effective in reorganizing some macromolecules into a structural arrangement homologous to life forms.

The second type of experiment dealing with the astrophysical properties of micro-organisms could be conducted in the laboratory. First, masses, sizes, shapes of selected species of bacteria, spores, seeds, etc., could be measured. Other important physical studies which bear on interplanetary biomigration could be investigated, e.g., the determination of the magnitude of electric charges which organisms may acquire and retain, and their behavior in electric fields; the absorption and emission properties with respect to various types of radiations, radiation pressure effects, heating by radiation, etc., and in general all factors which may play a role in the interaction of organisms with physical forces such as light pressure, force fields, convection, etc., and which could be responsible for automigration and determination of the organism's condition in space. Such data would be of great use to the space scientist in theoretically determining the probabilities of transport of such organisms by light pressure, Poynting-Robertson effect, and other mechanisms across space to other celestial bodies.

Finally, samples of the content of the upper atmosphere, and the exosphere for micro-organism density will give useful data in determining the probabilities of escape of the relatively heavy micro-organisms from a planet. The sampling experiments would attempt to obtain data on the numbers and types of organisms at a range of heights in the atmosphere and to various distances in the exosphere. This data would be of value in checking the efficacy of natural physical forces in abetting escape of organisms from the earth. If organisms are found in measurable numbers in space, a method of determining what percentage, if any, are on hyperbolic orbits (geocentrically speaking) should be derived.

It is apparent that two aspects of these experiments are involved:

1. There is the purely physical aspect of the problem in the consideration of the probabilities of inorganic particles with the masses, sizes, etc., of micro-organisms being transported as described above, and
2. There is the bio-aspect of the problem concerning survival of micro-organisms under the various atmospheric and space conditions encountered and for the time durations involved.

With the survival, astrophysical, and sampling data, panspermia hypotheses could be re-examined and the actual dangers of contamination of other celestial bodies by various types of space flight operations determined, and whatever sterilization measures required beyond those affected by space conditions themselves could be derived and implemented. Guided by knowledge of the extent of contamination probabilities, plans for the methodical scientific exploration of other planets can be laid. For example, an interplanetary probe not landing on Mars but merely grazing the upper atmosphere, or an artificial satellite of Mars or Venus might then be launched, knowing what risk of contaminating the planet itself exists, and the opportunities of obtaining important data toward answering fundamental questions in biogenesis and organic evolution need not be destroyed.

In view of the scientific gains by contamination avoidance, as described by Dr. Lederberg,⁽⁸⁾ both in the question of neo-biotic* synthesis of large molecules and in testing the validity of the panspermia hypothesis; and in view of the fact as we were told by Dr. Donovan⁽¹⁰⁾ that lunar probes

* Neo-biotic is defined as leading to the formation of biologically active states.

have been authorized and will be launched in a matter of months, the contamination question assumes rather a high priority.

In a research program such as sketched here, the early collaboration of biologists with other scientists and engineers working on space flight problems would be highly desirable.

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